LLNL Environmental Restoration Division Standard Operating Procedure	TITLE: Hydraulic Testing (Pumping)
APPROVAL Date _____ _____ Environmental Chemistry and Biology Group Leader	PREPARERS: T. Berry*, J. Chiu*, R. Ferry*, S. Nelson*, and E. Nichols* REVIEWERS: T. Carlsen and V. Dibley
APPROVAL Date _____ _____ Division Leader CONCURRENCE Date _____ _____ QA Implementation Coordinator	PROCEDURE NUMBER: ERD SOP-3.4 REVISION: 2 EFFECTIVE DATE: December 1, 1995 Page 1 of 12

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1.0 PURPOSE

To determine the hydraulic properties of water-bearing materials by controlled pumping of a well for 1–8 hours (short term) and up to 24 hours or longer (long term), and to evaluate the degree to which relatively permeable sediments are hydraulically connected vertically and horizontally.

2.0 APPLICABILITY

This procedure is applicable to hydraulic testing by pumping. Pumping tests provide results that are more representative of average aquifer characteristics than those predicted by slug tests. Pumping tests require a greater degree of activity and expense and are not always justified for all levels of investigation. For example, slug/bail tests may be acceptable at the reconnaissance level, whereas pumping tests are usually performed as part of a feasibility study in support of designs for aquifer restoration. The aquifer characteristics that can be obtained from pumping tests include hydraulic conductivity (K), transmissivity (T), specific yield (SY) for unconfined aquifers, and storage coefficient (S) for confined aquifers. Single well pumping tests of short duration, which monitor the water level in the pumping well only, can be used to determine transmissivity and hydraulic conductivity but not specific yield or storage coefficient. The test data are analyzed using graphical solutions and/or appropriate computer software packages.

3.0 REFERENCES

3.1 Boulton, N. S. (1954), "The Drawdown of the Water-Table under Non-Steady Conditions Near a Pumped Well in an Unconfined Formation," *Proc. Inst. Civil Eng.* **3**, paper 5979, p. 564.

3.2 Boulton, N. S. (1954), "Analysis of Data from Non-Equilibrium Pumping Tests Allowing for Delayed Yield from Storage," *Proc. Inst. Civil Eng.*, **26**, paper 6693, pp. 469−482.

3.3 Bower, H. (1978), *Groundwater Hydrology*, McGraw-Hill, New York, N. Y.

3.4 Bower, H. and R. C. Rice, (1976), "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells," *Water Resour. Res*, **12**(3).

3.5 Bredehoeft, J. D. and S. S. Papadopoulos (1980), "A Method for Determining the Hydraulic Properties of Tight Formations," *Water Resour. Res.* **16** (1), pp. 233−238.

3.6 Cooper, Jr., H. H., J. D. Bredehoeft, and S. S. Papadopoulos (1967), "Response of a Finite-Diameter Well to an Instantaneous Charge of Water," *Water Resour. Res.*, **13**(1).

3.7 Cooper, Jr., H. H. and C. E. Jacob (1946), "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-Field History," *AGU Trans.*, **27**(4), pp. 526−534.

3.8 Earlougher, R. C. (1977), *Advances in Well Test Analysis*, Society of Petroleum Engineers of AIME.

3.9 Ferris, J. G. and D. B. Knowles (1954), "The Slug Test for Estimating Transmissivity," *USGS Groundwater Note 26*.

3.10 Freeze, R. A. and J. A. Cherry (1979), *Groundwater*, Prentice-Hall, Englewood Cliffs, N.J.

4.0 DEFINITIONS

4.1 Aquifer Test

An aquifer test is a controlled field experiment performed to determine the hydraulic properties of water-bearing materials.

5.0 RESPONSIBILITIES

5.1 Division Leader

The Division Leader's responsibility is to ensure that all activities performed by ERD at the Livermore Site and Site 300 are performed safely and comply with all pertinent regulations and procedures, and provide the necessary equipment and resources to accomplish the tasks described in this procedure.

5.2 Field Personnel

Field personnel are responsible for conducting and documenting hydraulic testing according to this procedure.

6.0 PROCEDURES

6.1 Discussion

Wells are selected for extended pumping based on location relative to contaminant plume(s), expected flow rate, and proximity to observation wells. Long-term pumping tests may last from 4 days to 1 week, typically with 1 day of background monitoring, 1 day or more of actual pumping, and 1 day of recovery observations. In all phases of the long-term test, barometric pressure is monitored continuously by a barometric pressure transducer. The duration of a test is determined by the test objectives and the aquifer properties. A test duration of one to several days is desirable, followed by a similar period of monitoring water-level recovery. Partially confined aquifers and partially penetrating wells may have a shorter test duration. A knowledge of the local hydrogeology and a clear understanding of the overall objectives of the test, are necessary to determine the test duration. The effect of any hydrogeologic boundaries should also be considered. Pumping or recovery monitoring can be discontinued if the water levels become constant with time. During pumping, this may indicate that a hydrogeologic recharge boundary has been intercepted and that additional testing would not yield any more useful information.

If indicated on the test protocol provided by the task leader/study area leader, a step-drawdown test may be performed. The general data collection procedure for this test is the same for a constant-rate test, except drawdown data only need to be collected from the pumping well (if the step test is to be followed by a constant-rate drawdown test). For this reason, it is often possible to conduct a 2 to 3 h step-drawdown test on the pumping well, while instrumenting observation wells for the constant-rate test. If done, allow sufficient time for the aquifer to recover prior to starting the constant-rate test. The objectives of a step-drawdown test are to 1) determine the magnitude of non-Thesian well losses caused by friction within the well screen and the sand pack, or 2) determine the optimum pumping rate for a constant-rate test. A step test is also useful in evaluating the progress of well development. To perform a step-drawdown test, the well should be pumped at approximately three different rates (for example, 5, 10, and 25 gallons per minute). Generally, 1 h for each step is sufficient. It is not necessary for drawdown to stabilize before proceeding to the next step.

6.2 Office Preparation

6.2.1 Review the associated SOPs, Site Safety Plan, and other appropriate documents.

6.2.2 Coordinate schedules/actions with the task leader/study area leader regarding site access and availability of necessary pumping test equipment.

6.2.3 Obtain test protocol from the task leader/study area leader or project hydrogeologist. This protocol should include specific test details such as which wells are to be monitored, pumping rates, test duration, and other site- and task-specific variables.

6.2.4 Review the operator's manual provided with the electronic data loggers, if appropriate.

6.2.5 Obtain equipment listed in the Equipment Checklist (Attachment A) and verify it is properly operating . Make sure the electronic data logger is fully charged, if appropriate. Always bring additional transducers in case of malfunctions.

6.2.6 Obtain the Hydraulic Test Logbook. Assemble a sufficient number of field forms to complete the field assignment to include:

1. A site map of the area to be monitored with all observation wells highlighted.
2. Aquifer Test Data Sheets (SOP 3.3, "Hydraulic Testing (Slug/Bail), Attachment B) for each well to be monitored.
3. Schedule of water samples to be taken, and water sampling and Chain-of-Custody forms (if appropriate).
4. A list of the observation wells and their construction details, listed in the order in which water levels are to be measured.

6.2.7. Initiate steps to collect, treat, and dispose of purged water according to the appropriate version of SOP 4.7, "Treatment and Disposal of Well Development and Well Purge Fluids."

6.3 Field Preparation

6.3.1 Check equipment for proper function as follows:

1. Pumps should be submersible or turbine type. The pumping well should be properly developed at least one week before testing. Verify that the existing pump is sufficient for the estimated flow rate.
2. Verify that an orifice, weir, flow meter, container, or other type of water measuring device is available to accurately measure and monitor the discharge from the pumping well.
3. Verify that sufficient discharge hose or pipe is present to transport the discharge water from the pumping well to conform with discharge requirements.
4. Verify that an orifice valve manifold or gate valve is located on the discharge pipe to control the pumping rate.
5. Verify that a sampling port is near the wellhead for water quality sampling.

6.3.2 Calibrate all gauges, transducers, flow meters, etc., before conducting pumping tests (SOP 3.2, "Pressure Transducer Calibration"). Document instrument calibration in the Hydraulic Test Logbook and file copies of the documentation with the test data records. The calibration records should consist of laboratory measurements, and if necessary, any on-site zero adjustment or calibration. Where possible, check all flow measurement devices on site using a container of measured volume and a stopwatch.

6.3.3 Extend transducer wires to appropriate wells. Wires should be secured with duct tape where they cross walkways and other paved surfaces. To prevent disturbances, wires should be marked with flagging tape if strung across unpaved areas.

6.3.4 Decontaminate each transducer and cable as specified in the sampling plan and in SOP 4.5, "General Equipment Decontamination."

6.3.5 If the pumping duration is expected to exceed 2 h, water levels and barometric pressure at the test site should be monitored for at least one day prior to pumping. This information allows the barometric efficiency of the aquifer to be estimated, and indicates if the aquifer is experiencing changes in head due to recharge, pumping in the nearby area, or diurnal variations. Barometric pressure is recorded during the test with an on-site barograph or barometric pressure

transducer in order to correct water levels for any fluctuations that may occur due to changing barometric conditions. Pretest water-level trends are projected into the pumping phase of the test. These trends and barometric changes are used to adjust water levels measured during the test to be representative of the hydraulic response of the aquifer due to test well pumping.

6.3.6 Generally, 4–8 wells are instrumented with pressure transducers and about 10–15 additional wells are monitored with an electric water-level meter. Water levels in all wells within a 500- to 1,000-ft radius of the pumping wells are measured frequently during the test. For wells with transducers, water levels are measured every 15 min during the background phase, and on a logarithmically increasing frequency ranging from 1 second to 15 minutes during the pumping and recovery phases.

6.3.7 Water-level measurements in non-instrumented wells are measured two to four times during the background phase and every one to three hours during the pumping an recovery phases of the test.

6.3.8 Water levels should be measured as specified in SOP 3.1, "Water Level Measurement." To keep measurements equally spaced in time, water levels should be taken in the same order each sampling period. Simultaneous readings at wells are not necessary. It is very important that depth-to-water readings are measured accurately and recorded at the exact time. To complete the pumping test, pressure transducers and electronic data loggers can be used to reduce the required field personnel hours. A typical Aquifer Test Data Sheet is shown in SOP 3.3 "Hydraulic Testing (Slug/Bail)," Attachment B.

6.4 Operation

6.4.1 A pumping test monitors the water levels in the pumping well and observation wells as the pumping well discharges at a constant rate.

6.4.2 Record the following data on the Aquifer Test Data Sheet (SOP 3.3, Attachment B) at the time the test is performed.

1. Site Location. Brief description of general site location.
2. Well ID. Unique number assigned to each well.
3. Date. The date when measurements are taken.
4. Distance from pumped well (ft). Distance to the observation well from the pumping well in feet and tenths of feet.
5. Personnel. Initials of personnel performing field measurements or collecting samples.
6. Static Water Level. Depth to water, in tenths and hundredths of feet, in each observation well before pumping.
7. Test Start Date. The date when pumping began.
8. Test Start Time. Time in hours:minutes:seconds at which pumping began using 24-h clock (e.g., 08:37:00 for 8:37 a.m.; 19:12:00 for 7:12 p.m.).
9. Test End Date. The date when pumping ends.
10. Test End Time. Time in hours:minutes:seconds at which pumping ended using 24-h clock (e.g., 08:37:00 for 8:37 a.m.; 19:12:00 for 7:12 p.m.).

11. Average Pumping Rate. Time-weighted average of all entries recorded in the Pumping Rate (gal/min) column.
12. Measurement Methods. Type and serial number of instrument used to measure depth to water (this may include steel tape, electric sounding probes, Stevens recorders, or pressure transducers).
13. Comments. Appropriate observations or information for which no spaces are specifically provided.
14. Time. Record the time of water-level or flow-rate measurement in hours, minutes, and seconds, using a 24-h clock.
15. Depth to Water. Depth to water, in tenths and hundredths of feet.
16. Pumping Rate. Flow rate of pumping well measured with an orifice, weir, flow meter, container, or other device.
17. Record time pump is stopped.
18. Time. Record the time of water-level or flow-rate recovery measurements in hours, minutes, and seconds, using a 24-h clock.
19. Depth to Water. Depth to water, in tenths and hundredths of feet.

6.5 Long-Term Pumping Test Procedure

6.5.1 Day 1

1. Power up data logger(s) and synchronize clock time.
2. Lower the transducers into their respective wells. Monitor the logger channel corresponding to the well to ensure the transducer is not lowered too far below the water. Attach a transducer wire to a nearby ballard/post to prevent slippage during the test.
3. Connect barometric pressure transducer to one of the data loggers.
4. Log data at 30-minute intervals.

   Note: Set the transducers for one logger and begin logging. To allow for more background data to be collected, lower the transducers for the next logger.
5. Take one round of hand-measured water levels in all wells, including wells with transducers ("complete" round). Note the date, time, depth-to-water, and observer's initials in each well's log book. Check the data loggers.
6. After 2 hours, take a second round of water levels. However, it is not necessary to obtain hand measurements from wells with transducers ("normal" round).

   Note: To ensure logging is being completed, each round should include a check mark on the data logger and the time should be noted on each transducers readout. Look for anomalies such as sudden changes on a particular channel. If a change occurs, obtain a manual measurement of the well in question to confirm the change.
7. If time permits, take another "normal" round of water-level measurement. At least 2 rounds of water-level measurements should be collected before the end of the day.

8. When the pumping test is monitored by an electronic data logger and pressure transducers, most of the data is stored electronically or on computer diskettes or tape. The data memory location numbers from the data dump start and finish should be noted at the end of each day. This information is transferred directly to the main computer and analyzed. To document the test, test data forms are kept in files with supplemental information and a computer printout of the data in the files.

6.5.2 Day 2

1. Take a complete round of water-level measurements and check the data loggers.
2. Set up the plumbing and flow meter from the wells to water tanks, or treatment facility.
3. Take a normal round of water-level measurements and check the date loggers.
4. Start the pump test at the specified flow rate. Measure the flow rate (Q) using totalizer, or note flow on flow meter.
5. After pumping has begun, a normal round of water-level measurements must be taken approximately every 1–3 hours. Check the data logger and a measurement of Q.
6. Dump Campbell logger data to a cassette tape and record the memory location numbers from start to finish.

6.5.3 Day 3

1. Check logger(s).
2. Continue water-level measurement rounds through the day and evening.
3. Dump Campbell logger data to the cassette tape and record the memory location numbers from start to finish.

6.5.4 Day 4

1. Check logger(s).
2. Take a complete round of water-level measurements.
3. Before turning off the pump, take a normal round of water-level measurements.
4. Set the pumping well data logger to begin fast logging intervals (also done prior to the start of pumping) and turn off the pump for 5 seconds after start of fast logging.
5. Start recovery water-level measurements approximately 1–3 hours after the pump is off. At least 2 rounds (or more) of water-level measurements must be taken before the end of the day. It is not necessary to take manual water-level measurements through the night.
6. Dump Campbell logger data to a cassette tape and record the memory location numbers from start to finish.

6.5.5 Day 5

1. Take a complete round of water-level measurements.
2. Turn off the data loggers.
3. Dump any remaining Campbell logger data to a cassette tape and record the data memory location numbers from start to finish.
4. Pull the transducers from the wells and wind up the transducer wires.
5. Dump the data logger(s) data to a double-density floppy diskette using an available computer in the LLNL office (see logger dumping instructions). Make a backup to be kept at LLNL.

6.6 Constant Rate One-Hour Drawdown Test

6.6.1 Drawdown tests are conducted on wells with electric submersible pumps to determine transmissivity (T) and hydraulic conductivity (K) of the water-bearing zone(s). The optimum pumping rate for the test (estimated during final development) is one that puts maximum stress on the aquifer for 30–45 minutes, but does not draw the water level into the well screen or pump intake. Reaching a relatively "steady state" before ending the test is also important, because the rate of drawdown at the end of the test doesn't change or is slower compared to the rate of drawdown at the beginning of the test. This provides sufficient data to form a curve that can be matched to a type-curve allowing T an K to be calculated.

6.6.2 Water levels are measured in the pumping well and some observation well by a pressure transducer and recorded by a data logger. In addition, water levels in some wells are measured manually with an electric water level probe.

6.6.3 All information collected during the test should be recorded on the Aquifer Test Sheet (SOP 3.3, Attachment B).

6.6.4 Information Prior to Set Up:

1. Check with DMG to determine if purge water needs collection/treatment based on analytical data obtained from water samples collected during development.
2. Flow rate for the test (estimated during final development).
3. Make, model, voltage, and horsepower of pump is necessary to obtain the correct control box.
4. Screen interval of the well and depth of the pump intake to avoid pumping the well dry or into the screen.
5. Check with Hydrogeologic Group Leader to determine if any surrounding wells will communicate with the test well.

6.6.5 Set Up Procedures:

1. Set up flow meter and evacuation hoses, and plumb into collection tank.
2. Plug the extension cord into the generator and into the pump control box. The extension cord on/off switch box should be "OFF."

3. Manually record depth-to-water measurements in all wells to be monitored and note the time on the aquifer test sheets.

4. Set up the data logger and lower the transducer(s) to the maximum allowable depth as specified by the transducer(s) used.

5. Firmly attach the transducer line to a nearby anchor with duct tape, such as a post or a tree (not directly to the well's stove pipe) so it will not slip. Record the static logger readout.

6. While observing the logger readout, raise the transducer 1 ft. The logger readout should decrease by 1 ft. If the logger readout change corresponds to the actual change, lower it back down. If not, the transducer is malfunctioning and needs to be repaired.

7. Prime the well discharge tube by turning the pump on long enough to bring water to the first valve. Check for leaks and then shut off the pump. If necessary, repair any leaks with Teflon tape. Allow the water level in the well to recover about one-tenth of a foot of static before starting the test.

8. After the water level has sufficiently recovered, set the data logger to log at:

   - 1-second intervals for 20 seconds.
   - 2-second intervals for 40 seconds (20 intervals)
   - 5-second intervals for 1 minute (12 intervals)
   - 10-second intervals for 1 minute (6 intervals)
   - 30-second intervals for 7 minutes (14 intervals)
   - 1-minute intervals (every minute) thereafter.

   Note: These intervals are already set on the Campbell logger and logging will commence when turned on.

9. To begin the test, turn on the logger 5 seconds before starting the pump. Preferably, start logging on the "even" minute and start pumping after 5 seconds (e.g., 10:00:00 "logger on," 10:00:05 "pump on").

10. Check flow rate (Q) using a 5-gal bucket or the totalizing flow meter on the collection tank. Q should be measured at regular intervals during the test (approximately every 10 minutes), more often at the beginning (approximately every 3–5 minutes).

11. At the beginning of the test, verify that the transducer is reading correctly by taking a manual water-level measurement with the water level probe.

    Note: If the transducer is not reading correctly, stop the test. Allow the water level to return to static and restart the test using a different transducer.

12. When the water level has become relatively stable (some drawdown will be continuing very slow [i.e., 0.1 ft/1–5 minutes]), pump for a few more minutes and turn off the logger. Usually, a minimum of 30 minutes is required and tests may run up to an hour or more, depending on the well.

13. Reset logging intervals for 5 seconds before turning off the pump. Continue logging recovery until 90 percent of the water level has returned to the pre-pumping level.

14. Break down the equipment.

15. If using the Campbell logger, the data should be dumped to the cassette tape and the memory location numbers of the test start and finish should be recorded.

16. Record the tape (Campbell or Hermit) of the logger used and the type and serial number of the transducers(s).

6.7 Field Post Operation

6.7.1 After pumping ceases, continue to measure recovering water levels to verify results obtained from the pumping portion of the test. The recovering water levels in the pumping well and the observation wells are measured immediately following cessation of pumping; the recovery period should be at least half the length of the pumping portion of the aquifer test. The decision to cease monitoring of water levels should be based on aquifer recovery.

6.7.2 Decontaminate or dispose of equipment per SOP 4.5.

6.7.3 If using an electronic data logger:

1. Stop logging sequence.
2. Save memory, and disconnect the battery at the end of the testing activities.

6.7.4 Replace testing equipment in storage containers.

6.8 Office Post Operation

6.8.1 Inventory equipment and supplies. Repair or replace all broken or damaged equipment and expendable items.

6.8.2 Return equipment to storage area, and report incidents of malfunctions or damage.

6.8.3 Review field forms for completeness.

6.8.4 Deliver logger data and original forms to the Data Management Group and copies to the Project Hydrogeologic Group Leader (HGL).

6.8.5 Return logbooks to the Document Control Officer.

6.8.6 Interpret aquifer test field results with Project HGL. Analyze data using an appropriate analytical solution.

6.8.7 Send data logger or pressure transducers to the factory for recalibration, if needed.

7.0 QA RECORDS

7.1 Logbooks

7.2 Hydraulic Test Data Sheet

8.0 ATTACHMENT

Attachment A—Equipment Checklist

Attachment A

Equipment Checklist

Equipment Checklist

____ Appropriate references and calculator

____ Barometric pressure transducer or recording barograph (for tests conducted in confined aquifers).

____ Calculator—data logger

____ Discharge hose or pipe

____ Duct tape

____ 12-volt battery (fully charged)

____ 230-volt generator

____ Electric water-level indicator

____ Electronic data logger (if transducer method is used)

____ Extension cord and on/off switch box

____ Five-gallon bucket

____ Flow meter

____ Hoses—1 in. and 3/4 in.

____ Interface probe

____ Pump control box (must equal voltage and horsepower of pump)

____ PVC fittings (elbows, unions, etc.)

____ Semilog graph paper (if required)

____ Signet flow meter

____ Steel tape (subdivided into tenths of feet)

____ Stopwatch or watch with second hand

____ Submersible pumps or turbine type.

____ Tape measure (subdivided into tenths of feet)

____ Water-level measuring device

____ Water-measuring device (i.e., orifice, weir, flow meter, or container)

____ Water-pressure transducer(s) and cables

____ Waterproof ink pen and logbook